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Development of Geophysical Methods for Coal Exploration in Alberta

Projects supported in part
by the Alberta/Canada
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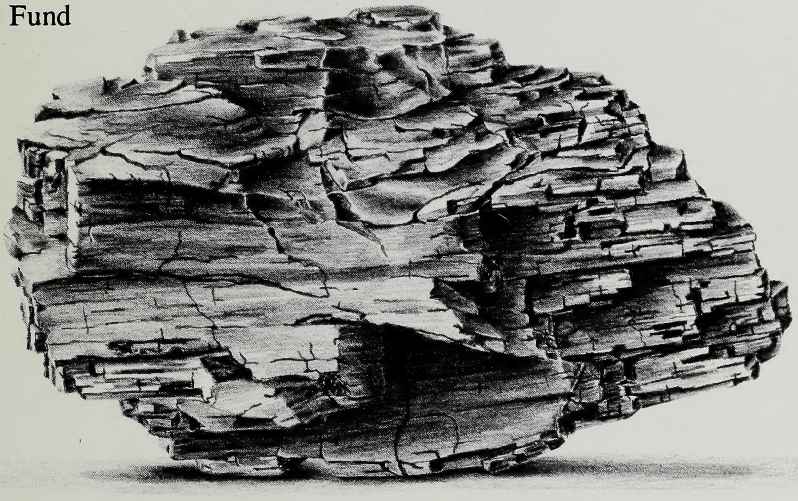

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Foreword

Beginning in 1976, numerous projects were initiated in Alberta by industry and academic research institutions to help make better use of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rested with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities focused primarily on coal, energy conservation and renewable energy, and conventional energy resources. In 1988/89, a hydrogen research component was added.

Administration for the A/CERRF program was provided by staff within the Research and Technology Branch of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments. It also monitors the progress of these projects in an overall program of improving the production, transportation and marketability of Alberta coals.

The A/CERRF program ended on March 31, 1991 and the support it provided has been replaced by funding from the Alberta government.

A series of technology transfer booklets begun in 1986 with A/CERRF support continues to make research results available to industry and others who can use the information.

This service will continue until all A/CERRF projects have been described.

For more information about other publications in the series, please refer to page 19.

Development of Geophysical Methods for Coal Exploration in Alberta

Exploration geophysics is an offshoot of physics, chemistry and mathematics. The techniques used in geophysics are based on principles such as gravitational and magnetic attraction, optical reflection and refraction, and elements of electricity and electromagnetic theory. All these principles are used in instruments and methods intended to locate geologic structures having some economic value. Therefore, geophysical techniques are becoming increasingly important in coal exploration.

For decades, a combination of drilling and surface geophysical measurement techniques has been the most cost-effective method of acquiring information about the deep oil and gas targets associated with petroleum exploration and development. In coal exploration on Alberta's plains, however, subsurface information is obtained simply by drilling on a grid. Because this does not provide many data points, the probable conditions existing between drilled points must be estimated. If additional information is desired, more drilling must be done. This causes a rapid increase in costs.

An alternative is to employ geophysical techniques developed recently for shallow, subsurface targets. The theory and practice of these methods was described in a handbook published in 1982 by the Coal Mining Research Centre in a research project funded by A/CERRF.

Subsequently, several research projects were administered by the Alberta Office of Coal Research and Technology, and funded in part by A/CERRF, to demonstrate the suitability of geophysical methods for exploring and developing plains coal resources. Also, the ability of some geophysical methods to detect coal in foothills and mountainous settings was investigated. These projects are described here.

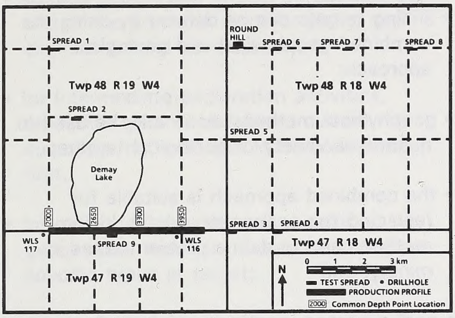
Reflection Seismic Investigations of Western Canadian Coalfields

In a study carried out in 1983 at The University of Calgary, the suitability of the reflection seismic method was tested in conditions typical of western Canadian coal deposits. In particular, the method was used to determine coal seam continuity and for delineating the gross and fine structures of shallow coalfields in Alberta. A "Betsy" seisgun was used as the source of seismic energy, and testing was conducted at the Camrose and Coal Valley mines, located in the plains and foothills regions, respectively, as well as the Luscar and Grassy Mountain mines, located in the mountain region. Interpretation of the seismic data for these sites was made possible by consulting an existing drill-hole data base.

At Camrose, coherent reflections from a coal zone between 70 and 110 m below the surface were recorded along a 5-km profile. Variations in reflection amplitude and character were interpreted qualitatively in terms of the relative thickness and separation of two main coal seams. Channel washouts, faults with throws of 5 m or greater, and effects of differential compaction were resolved from the seismic data.

Studies at the Coal Valley Mine in the foothills showed that good data can be obtained in structurally disturbed areas with mild deformation. In the mountain region, however, it was found that the seismic method was not appropriate in areas with strong deformation. Deep weathering, variable topography and rapid lateral changes in reflector dip were thought to be the primary reasons for poor data quality.

Seismic test site near Camrose, showing locations of test spreads and production profile.



(Source: Reflection Seismic Investigations of Western Canadian Coalfields, Lawton, D. C. and M.B. Bertram, The University of Calgary, 1983.)

The seisgun was found to perform well in areas with a shallow water table and a zone of interest within 350 m of the surface, but its effectiveness decreased dramatically if the overburden was both thick (30 m) and dry.

It was concluded that the seismic method was appropriate for evaluation of plains and foothills coal deposits. Because it can provide continuous subsurface coverage between drill holes, the technique can reduce the density of the drill-hole pattern and reduce drilling costs.

Potential of Geophysical Techniques for Coal Exploration

During 1986, researchers at the Coal Mining Research Company (formerly known as the Coal Mining Research Centre) carried out a review of geophysical methods used in coal exploration, and outlined several potential applications for this technology in Alberta. The study was essentially a summary of the state-of-the-art, and covered geophysical methods such as seismic, nuclear, electrical and caliper logging. This investigation served as a basis for several other projects.

Surface Geophysical Coal Exploration in the Alberta Plains

From 1984 to 1986, the Coal Mining Research Company, the Alberta Research Council and Geo-Physi-Con Co. Ltd., carried out a geophysical investigation at three Alberta coal mines. This study was funded by TransAlta Utilities Corporation, Luscar Ltd., Fording Coal Limited, Esso Resources Canada Ltd., Alberta Research Council, Saskatchewan Power Corporation and A/CERRF, as represented by the Alberta Office of Coal Research and Technology.

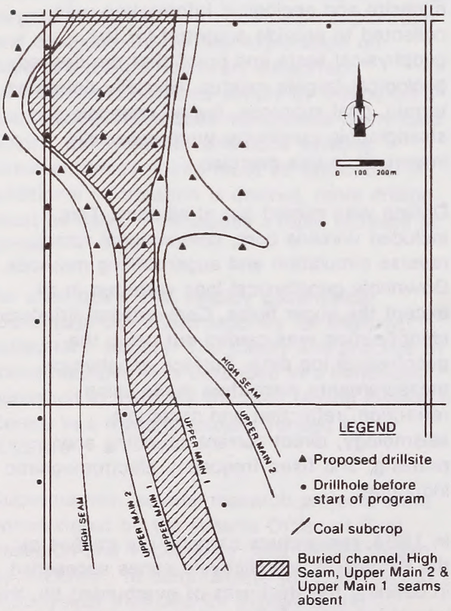
The subsurface conditions at the Paintearth, Highvale and Genesee mines were studied to test several geophysical methods. Air photo reconnaisance maps were prepared for each minesite and geological information was collected to provide a control for the geophysical tests and proof that the desired geological targets existed. Glacially deformed terrain, coal subcrops, buried channels and stratigraphic continuity were especially important in this exercise.

Drilling was carried out at all sites. This included wireline core, conventional rotary, reverse circulation and auger drilling methods. Downhole geophysical logs were run in all except the auger holes. Conventional lithologic identification was carried out using the geophysical log data. Surface geophysical measurements were then made using refraction, reflection and crosshole seismology, direct current sounding and profiling, and fixed frequency electromagnetic induction.

In 1984, researchers carrying out studies at the Paintearth and Highvale mines succeeded in defining the thickness of overburden till, the lateral location of coal subcrops and the presence and lateral boundaries of glacially deformed bedrock. The next year, the following was accomplished in studies at the Paintearth and Genesee mines:

- coal subcrops were located using reflection seismic and direct current profiling geophysical methods;
- reflection seismic events were correlated to specific coal seams;
- coal continuity was established;
- the likelihood that refraction seismic velocity anomalies could be correlated to geological units in overburden was established; and
- an integrated surface geophysical/geological investigation was shown to be less costly than a conventional program without geophysics.

Hypothetical "drilling only" program

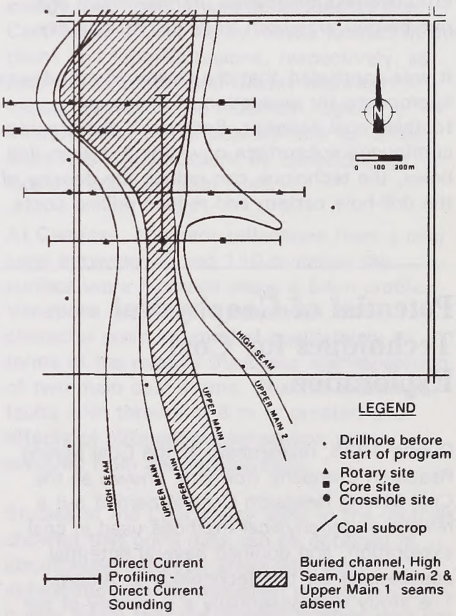


(Source: Surface Geophysical Coal Research Project 1984 to 1986, Final Report, Green, D. H., J. G. Pawlowicz, M. M. Fenton, C. Sterenberg, T. Sartorelli, J. Henderson and M. Pesowski, Coal Mining Research Company/Alberta Research Council/Geo-Physi-Con, January 1988.)

During the third and final year of the project, a detailed study was carried out at the Genesee Mine. This investigation showed the following:

- drilling targets can be defined by using the combined geophysical and geological approach;
- geophysical methods alone may be used to quantify a variety of geological targets;
- the combined approach is suitable for replacing the conventional infill drilling method used to define problem areas in mining; and
- coal subcrops, continuity and depth were successfully identified, as were areas of structurally deformed materials.

Hypothetical exploration program using surface geophysics and drilling


N
0 100 200m
HIGH SEAM
UPPER MAIN 2
UPPER MAIN 1
HIGH SEAM
UPPER MAIN 2
UPPER MAIN 1
LEGEND
• Drillhole before start of program
▲ Rotary site
■ Core site
● Crosshole site
Coal subcrop
Direct Current Profiling - Direct Current Sounding
▨ Buried channel, High Seam, Upper Main 2 & Upper Main 1 seams absent

(Source: Surface Geophysical Coal Research Project 1984 to 1986, Final Report, Green, D. H., J. G. Pawlowicz, M. M. Fenton, C. Sterenberg, T. Sartorelli, J. Henderson and M. Pesowski, Coal Mining Research Company/Alberta Research Council/Geo-Physi-Con, January 1988.)

Overall, the following recommendations were made as a result of this project:

- surface geophysics should be adopted as one of the principal tools for plains coal exploration and development;
- for intermediate exploration activities, reflection seismic and direct current sounding methods should be considered first;
- for mine planning, the selection of geophysical methods should be based on specific types of target;
- selection of the appropriate geophysical techniques should take into account the operating environment, the geologic framework, and a firm statement of the specific mapping objective which includes the depth of interest and the desired lateral and vertical resolution; and
- surface geophysical techniques are most effective when applied in an integrated geophysical and geological project.

Since the completion of this study, the tested geophysical methods have been adopted for use in the plains coal region. Both electrical and seismic techniques are being used.

Very Low Frequency Geophysical Methods in Coal Exploration

In a project carried out by Smoky River Coal Limited, very low frequency (VLF), high power signals, normally used for aviation and marine navigation, were used to help locate coal seams and fault subcrops in geologically complex mountainous terrain.

VLF signals from two U.S. stations were used to generate two sets of primary magnetic field lines at approximately right angles to each other. These magnetic fields induced eddy currents in conductive rock formations which, in turn, produced very low frequency secondary magnetic fields. The technique involved measuring and comparing the two magnetic fields, and relating these comparisons to known geological features. Also, the secondary magnetic field was used to determine apparent ground resistivity.

VLF electromagnetic and resistivity surveys were made on the South Pit area of the No. 9 Mine at Smoky River Coal Limited near Grande Cache. The South Pit was chosen for the study because outcrop and drill-hole data were available, the site was structurally complex, and it had variable thicknesses of unconsolidated overburden. Consequently, the VLF survey data could be correlated with the known geology of the site.

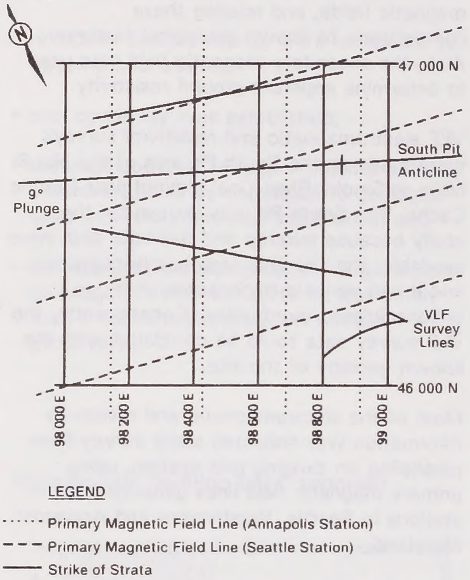
Most of the electromagnetic and resistivity information was collected along survey lines paralleling an existing grid system, using primary magnetic field lines generated by stations in Seattle, Washington and Annapolis, Maryland.

It was found that the VLF electromagnetic technique was of limited use in coal exploration, but it was useful in locating some thrust faults in areas of thin overburden. Also, this technique could differentiate between areas of thin and thick overburden.

VLF resistivity measurements, however, were found to be quite useful when used in conjunction with additional geological information. It was observed, though, that depth of penetration of the signal varied with the conductivity of the overburden. In the South Pit, unconsolidated overburden thicker than 12 m completely masked bedrock responses. While coal seams are expected to have higher electrical resistivity than the surrounding rock, weathering effects or the presence of groundwater can significantly reduce the resistivity response and prevent coal seams from being detected.

In assessing the cost-effectiveness of VLF techniques, it was concluded that VLF instruments are inexpensive to own and operate, and a considerable volume of data can be obtained rapidly. Nonetheless, it was emphasized that the stratigraphy must be well understood.

Orientation of Strata, Survey Lines and Primary Magnetic Field Lines

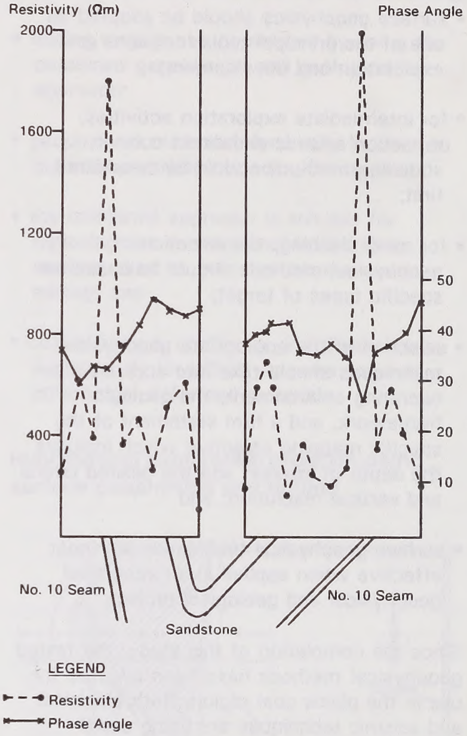


(Source: Very Low Frequency Geophysical Techniques in Coal Exploration, Wrightson, B. and D. Fawcett, Smoky River Coal Limited, 1985.)

The following nine-point procedure was proposed for mine operators who may be considering the use of VLF techniques:

- orient VLF survey lines perpendicular to the expected geological strike and select a transmitter station whose primary magnetic field lines run approximately parallel to the strike of the strata;
- collect initial information in an area of well-understood geology;
- drill-hole resistivity logs should be examined to determine which horizons, besides coal seams, may display high resistivity readings;
- the remainder of the data should be collected along closely spaced lines and plotted on resistivity profiles;

Orientation of Strata from VLF Resistivity



(Source: Very Low Frequency Geophysical Techniques in Coal Exploration, Wrightson, B. and D. Fawcett, Smoky River Coal Limited, 1985.)

- an apparent resistivity map should be plotted and contoured to highlight high resistivity trends;
- an overburden thickness map should be prepared to outline locations where bedrock resistivity measurements can be expected to be attenuated by a thick conductive overburden layer;
- the geology of the site can be extrapolated from the well-controlled lines into areas that are not as well characterized;

- if possible, VLF mapping information should be used in conjunction with outcrop mapping and drill-hole data; and
- whenever VLF electromagnetic data are collected, a Fraser contour map should be used to outline the locations of conductors.

Downhole Geophysics

When mining companies and geoscience consulting firms develop plans for mines, they need geotechnical and hydrogeological information that can be used in several ways. For example, it is needed to: predict highwall and spoil angles with confidence; reduce land disturbance; predict and better handle disturbances to the local groundwater regime; and reclaim mined-out areas rapidly and cost-efficiently. Consequently, a need exists for methods of obtaining geophysical and hydrogeological information faster and more economically than by core drilling, laboratory testing, piezometer setting and monitoring.

One alternative is to use geophysical techniques, including borehole methods which are potentially less expensive ways of providing considerably more information on overburden characteristics. While instrumentation for downhole geophysical measurement is well established, it remains to be demonstrated that quantitative interpretation of data for physical characterization can be achieved for Alberta's coal-mining environment.

In 1986, a joint-venture[1] group of companies and government agencies, under the leadership of TransAlta Utilities Corporation, began to study the practicality of using downhole geophysical techniques to obtain quantitative information about the geotechnical and hydrogeological characteristics of overburden materials, in particular those overlying Alberta's coalfields and oil sands deposits.

Initially, promising geophysical measurement methods were evaluated for their ability to provide low-cost information on 27 geotechnical and hydrogeological parameters. A review of current technology and applications revealed that several borehole geophysical methods were developed sufficiently to warrant testing in a coal-mining environment.

Subsequently, some of the participating companies supplied downhole geophysical data and corresponding measurements of geotechnical and hydrological properties to establish a data base from which correlations could be derived. This information was of limited use, however. Depth mismatches were discovered between the geophysical logs and the geotechnical and hydrological information. Also, it was found that individual participants reported data differently, and they used different calibration and correction routines. It was felt that improved data handling and analysis procedures were needed before operating mines could make practical use of quantitative log analysis.

The most complete data sets came from the Highvale coal mine, the Syncrude oil sands mine and the Battle River coalfield. Initial data processing indicated that correlations between some geophysical log values and geotechnical or hydrological parameters were possible, but the existing data needed to be refined. This refinement was necessary to eliminate erroneous data, to correct depth mismatches between the logs and the laboratory data, and to improve value averaging of the geophysical data with respect to the corresponding laboratory sampling intervals. Concurrent with this data refinement, an opportunity arose in 1988 to collect new data in a manner that was specifically designed for this project, using the careful control that by then was deemed necessary. Thus, geologists from the Alberta Research Council and the Coal Mining

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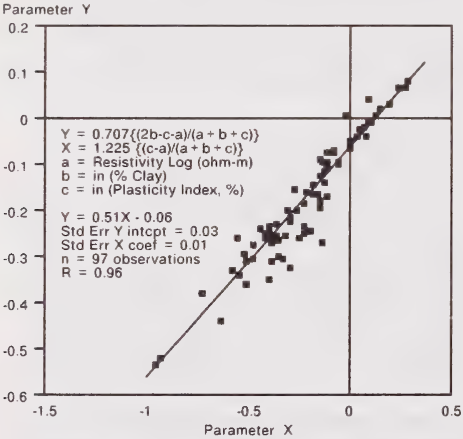
[1] Other participants in this project were: Fording Coal Limited, Manalta Coal Ltd., Monenco Consultants Limited, Suncor Inc., Syncrude Canada Ltd., Klohn Leonoff Ltd., Golder Associates, Terracon Geotechnique Ltd., Atomic Energy of Canada Limited, Saskatchewan Power Corporation, BPB Wireline Services Limited, N. Wade Holdings, Coal Mining Research Company, Alberta Research Council, University of Alberta, CANMET, Department of Western Economic Diversification, and the Office of Coal Research and Technology. Expert advice was provided by W.S. Keys of Geokeys and C.J. Mwenifumbo of the Geological Survey of Canada.

Research Company supervised the logging, sampling and laboratory analysis of samples from several drill-holes in the Big Valley area.

At this point in the project, it became evident that neutron, density and sonic geophysical logs gave good correlations with geotechnical data at one coal mine, while density and gamma logs showed reasonable correlations at one oil sands mine. Work on one of the geotechnical data sets demonstrated that improved data correction and analysis procedures were effective for strengthening the correlations. Results for direct shear test parameters, bulk density, Atterberg limits, and natural water content were particularly encouraging. Glacially deformed bedrock and undeformed bedrock were successfully differentiated using geophysical log data at two sites.

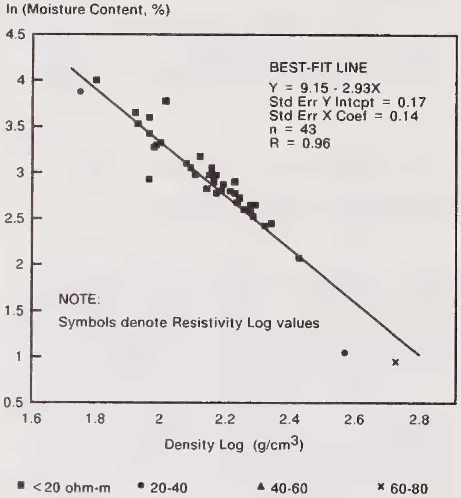
Resistivity vs % clay, Plasticity Index Highvale, Big Valley and Syncrude data.



(Source: Downhole Geophysics Project. 1986-1990. Final Report, Hoffman, G. L., M. M. Fenton and J. G. Pawlowicz, TransAlta Utilities Corporation, 1991.)

A preliminary evaluation of a full-wave sonic tool was completed. Field trials were conducted for a variety of logging methods, including natural gamma, temperature, several types of resistivity designs and a portable neutron moisture probe.

Moisture content vs density log Highvale and Big Valley data.



(Source: Downhole Geophysics Project. 1986-1990. Final Report, Hoffman, G. L., M. M. Fenton and J. G. Pawlowicz, TransAlta Utilities Corporation, 1991.)

Meanwhile, the data refinement stage focused on the relationships between geophysical log data and the following:

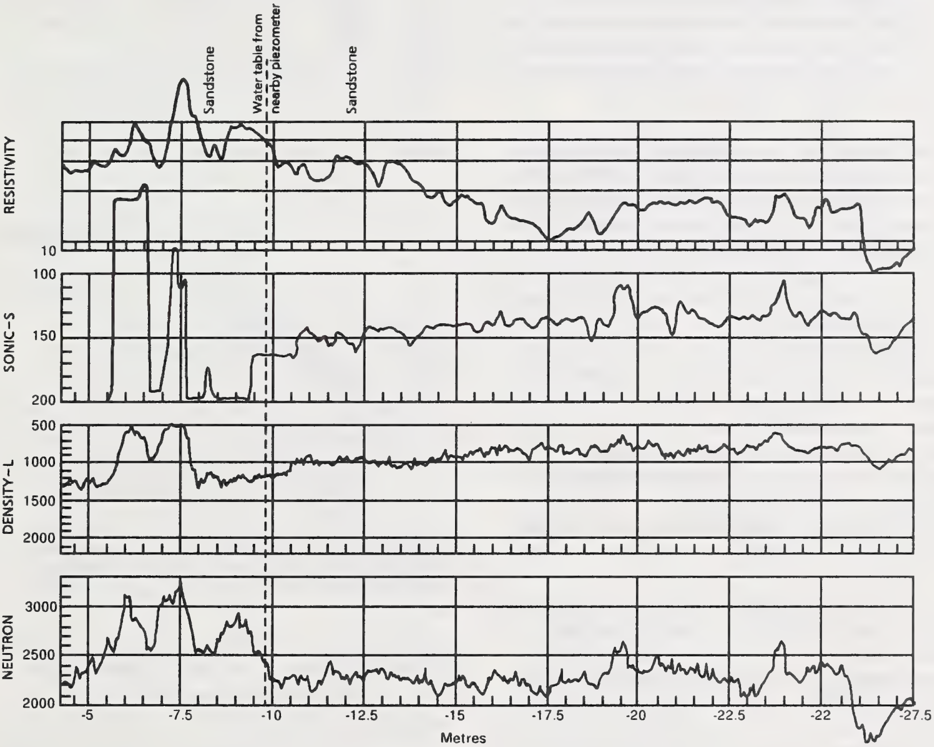
- geotechnical parameters;
- hydrological parameters; and
- glacially deformed bedrock.

Considerable effort was expended on improving procedures for sampling and analysis while maintaining rigid control over consistency and methods for reducing or eliminating the influence of extraneous factors on the data.

Thus, the final report for the project represents a detailed guide for the mining industry to follow in acquiring some of the best geophysical information available on Alberta's coalfields and oil sands deposits.

The response of neutron, density, sonic and resistivity logs in the vicinity of the water table in HV84-405 where the rock is uniform sandstone.

Wellname HV84405
Filename HV84405
Location HIGHVALE PIT 03
Elevation Reference Ground Surface



(Source: Downhole Geophysics Project. 1986-1990. Final Report, Hoffman, G. L., M. M. Fenton and J. G. Pawlowicz, TransAlta Utilities Corporation, 1991.)

Several conclusions were reached as a result of this added data collection and refinement. They were:

- data related to geotechnical and groundwater problems can be derived from geophysical logs and used to supplement data obtained by more expensive conventional means, such as core testing;
- the relationships between log response and geotechnical and hydrologic factors are site-specific and must be substantiated at each new site;
- quantitative log analysis by computer should be used to provide information that is not available from standard visual inspection of paper log charts;

- to avoid misleading conclusions, log interpretations should be done by people who are thoroughly familiar with the algorithms used and the geology and hydrology of the site;

- if geophysical logs are to be interpreted quantitatively, the equipment must be calibrated properly, logs must be checked for extraneous effects, and corroborating core samples must be taken carefully after the geophysical logs are examined;

- before quantitative log analysis can begin, certain actions must be taken to ensure that depth and drilling effects are corrected, and beds thinner than the limits of instrumental resolution are excluded or corrected; and

- all logs should be provided as paper printouts and in digital form.

Satisfactory correlations were obtained between several types of standard geophysical logs -- such as sonic, density, neutron, gamma caliper and resistivity -- and a variety of geotechnical parameters. These included moisture content, liquid and plastic limits, bulk and dry density, plasticity index and uniaxial compressive strength.

The sonic log gave the best indication of water table in both clay-rich and sandy material, while resistivity, neutron and density logs could detect the water table under some conditions.

It was recommended that a suite of logs including sonic, resistivity, neutron and density should be run and interpreted together for increased confidence in recognizing the water table.

For best results in detecting and evaluating glacially deformed bedrock, it was recommended that sonic, density, neutron and caliper logs should be run and interpreted together.

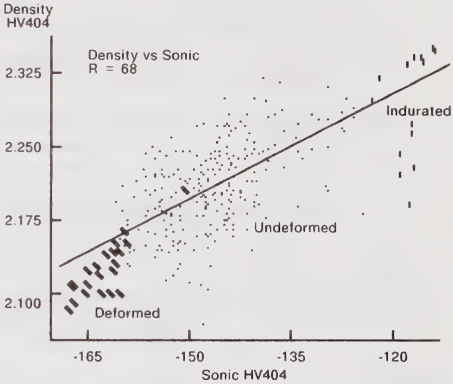
Example of good correlation from HV404, density vs sonic.

HV404, Pit 03, Highvale Mine

Pearson Product-Moment Correlation

641 total cases of which 288 are missing

	-Sonic...	Dens404	NN404	Gam404	Res404	Cal404
-Sonic404	1.000					
Dens404	0.680	1.000				
NN404	0.551	0.636	1.000			
Gam404	-0.250	-0.270	-0.671	1.000		
Res404	0.060	0.057	0.559	-0.579	1.000	
Cal404	0.120	0.266	-0.232	0.345	-0.677	1.000



(Source: Downhole Geophysics Project. 1986-1990. Final Report, Hoffman, G. L., M. M. Fenton and J. G. Pawlowicz, TransAlta Utilities Corporation, 1991.)

The spectral gamma log proved to be capable of identifying bentonite and montmorillonitic clays which cause problems for pit-wall stability.

From the evaluation of other geophysical tools, the following were concluded:

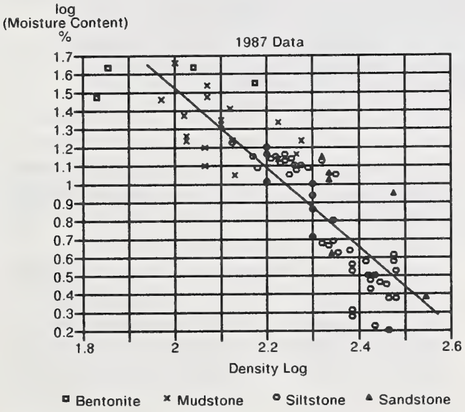
- a full-wave sonic log can provide data used in calculating rock properties that are applicable in mining and geotechnical engineering; and

- an acoustic-televiewer can provide high-resolution information on the strike and dip of bedding, and on the location, orientation and character of secondary porosity, such as in fractures and solution openings.

Finally, it was recommended that certain steps should be taken if a quantitative log interpretation program is to be implemented at a mine. These steps are:

- obtain geophysical log data in digital form;
- ensure that log quality is suitable for quantitative analysis; and
- ensure that core samples are taken and hydrogeological tests are carried out, with reference to the geophysical logs so that the depth correspondence between them is known with certainty.

log (Moisture Content) vs Density Log



(Source: Determining Geotechnical and Hydrogeological Parameters Using Downhole Geophysics in the Canadian Plains; Phase 2, TransAlta Utilities Corporation, May 1988)

In-Seam Coal Characterization

Overseas buyers of Alberta coal are demanding products that meet certain specifications more consistently than in the past. To coal producers, this means that more core holes must be drilled into coal seams and more laboratory analyses must be performed to obtain information about coal quality. As the number of core holes per coalfield rises, however, so do the costs of developing that field.

An alternative approach is to obtain coal quality information by less expensive geophysical methods. In the initial phase of this project, carried out at the Coal Mining Research Company, two primary methods of obtaining coal quality characteristics while the coal was still in the ground were identified from a literature survey. They involved nuclear spectroscopy based on elemental analysis, and an empirical method using geophysical logs and interpretive models.

In nuclear spectroscopy, samples are bombarded with neutrons to produce gamma-ray emissions. These emissions can be analysed to determine the presence and relative abundance of a wide variety of elements. Relative to the traditional drilling and assaying method, neutron spectroscopy is said to offer the following advantages:

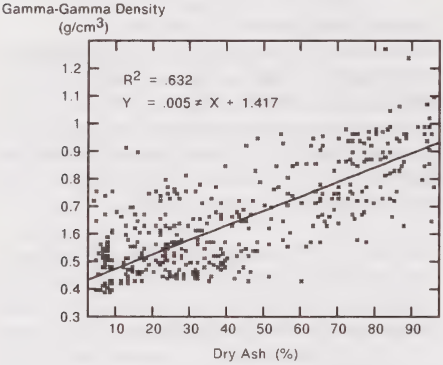
- the depth of the analysed sample is known accurately;
- the sample volume is relatively large;
- samples cannot be lost;
- there is only a small chance for human error; and
- analysis results are available immediately.

Available nuclear spectroscopy systems were reviewed and described. They included the Geosource T9D Sirolog system developed by the Commonwealth Scientific and Industrial Research Organization in Australia, as well as devices developed by Schlumberger, Princeton Gamma Tech, Scintrex and the United States Bureau of Mines. It was concluded that existing hardware is not capable of detecting all of the most important constituents of Alberta coals -- sulphur in particular -- but the potential does exist for developing equipment to provide the required information.

Meanwhile, several coal producers supplied logs of geophysical data and corresponding laboratory data on coal quality, allowing attempts at developing interpretive models to proceed, based on commercially available computer software.

Trials of interpretive programs to determine their suitability revealed that a good, qualitative correlation exists between logged geophysical density and laboratory-derived material densities, ash content and calorific value for coal from an Alberta plains mine.

Gamma-Gamma Density vs Dry Ash (Test Case - all holes)



(Source: In-Seam Coal Characterization, Phase 3, Coal Mining Research Company, March 1988)

Dual-log methods, which attempt to establish relationships with three coal properties simultaneously, produced less satisfactory correlations partly because of difficulties in estimating required mathematical constants. It was also found that a lack of consistency in obtaining the geophysical information in the field and relating it to laboratory analyses contributed to the data scatter.

The correlations, although very promising, were not precise enough to predict accurately the desired parameters in place of laboratory analysis.

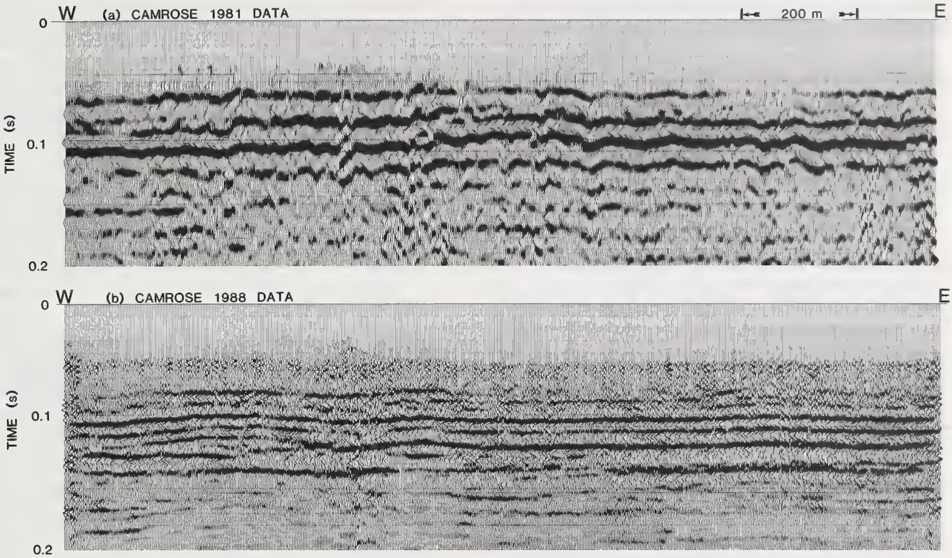
Seismic Modelling of Shallow Coalfields

In recent years, experimentation with a technique known as surface reflection seismography has indicated that it could be used to search for and evaluate coal in situ, but it has not been used to make quantitative measurements of the discovered coal. Rather, its use has been limited to determining whether coal is present. Nonetheless, it is believed that the reflection seismic method is capable of providing detailed information about the subsurface geology of shallow coal deposits. It has experienced only limited use in Alberta, primarily because certain technical difficulties are associated with attempts to obtain images of very shallow targets.

Thus, the objective of a study carried out at The University of Calgary was to solve these difficulties and demonstrate that quantitative interpretation of coal reflection seismic data is possible. The approach adopted was to compare synthetic seismograms with information from acoustic and density drill-hole logs obtained from coal deposits, and then perform two- and three-dimensional seismic modelling. It was believed that the thickness, geometry and number of coal seams in a deposit could be interpreted from the resulting data.

Approximately 100 density and sonic logs from the Highvale and Whitewood mines, and seven reflection seismic profiles from the Whitewood mine, were used as the data base. Geologic cross-sections corresponding to the seismic lines were used as reference. This information was interpreted so that changes in the seismic profile could be related to the coal geology by the use of modelling techniques.

Initially, one-dimensional modelling was tried as a method for obtaining quantitative interpretations of the coal seismic data. The purpose was to investigate the relationship between vertical resolution and frequency bandwidth of the data, and to determine whether variations in coal seam thickness and



Final stacked section from the seismic surveys over the Dodds-Round Hill coalfield near Camrose.

(Source: Seismic Modelling of Shallow Coalfields, Lawton, D.C., The University of Calgary, In: Proceedings of 1990 Fundamental Coal Science Workshop and Discussion, The University of Calgary, February 20, 1990.)

separation could be resolved using the reflection seismic method. For one well site, synthetic seismograms were generated with the density log alone, the sonic log alone and with both logs combined.

It was found that density information is indispensible for realistic modelling in the study area. Reflection character is determined almost entirely by density distribution with depth, since the seismic velocity of coal has been found to be similar to that of interburden. This is rare in seismic exploration. It was also shown that small variations in seam thickness and separation may lead to significant changes in the seismic response of the coal-bearing interval.

Subsequently, two-dimensional seismic modelling and physical modelling of a coal deposit revealed that density contrasts between coal and host sediments were primarily responsible for the reflectivity characteristics of plains coal. Signal resolution, however, was dramatically affected by the placement of data acquisition equipment in the field. It was shown that near shot-receiver offsets are preferred in seismic exploration for shallow coals. Further, it was observed that reflection seismic surveys can be useful in mapping coal pinchouts and wash-out zones ahead of mining operations.

A field seismic program was undertaken at a coal mine near Camrose. High-resolution reflection seismic data were collected over a 1.6-km seismic line, using a 96-trace Geometrics ES2420 seismic recording system. The Camrose site was chosen because it allowed field testing of approaches learned from the modelling work, and comparisons could be made with results from earlier seismic investigations at this site. The previous investigation in 1981 used a 48-channel DFS III recording system.

A significant improvement in data quality was achieved in the new survey. This was attributed to better energy coupling at the seismic source, improved receiver-spread geometry, a greater number of recording channels, high subsurface multiplicity, and the use of instruments with fast digital sampling rates and wide dynamic range. For example, reflections from the coal zone with dominant frequencies of up to 150 Hz were evident in the recent data, compared with 70 Hz in the 1981 data. All major coal seams could be mapped from the data, including splits and partings in a major coal zone. Using enhanced data processing methods, bed thicknesses in the 3-m range were resolved successfully.

To determine lateral resolution limits of the reflection seismic method applied to shallow coal exploration, physical modelling experiments were undertaken using the tank facility at the Geology and Geophysics Department. The model represented a delta-plain coal deposit with several wash-outs of different width, and was made from Plexiglas, polyvinylchloride, polyethylene sheeting and cement. A scale of 1:2 500 was used. Channels with scaled widths of between 25 m and 100 m were incorporated into the model and the thickness of the coal zone varied between 3 and 6 m. Reflection seismic data along two-dimensional profiles and a three-dimensional grid were collected. Three-dimensional data showed all the fine details of the model. It was found from the physical model work that channels greater than 25 m wide at a depth of 125 m can be resolved by the seismic equipment, and differences in channel thicknesses of 7 m are detectable under optimum conditions.

Mining Technical Committee

In recent years, several research organizations, companies and funding agencies in Alberta have been involved in geomechanical studies of Alberta's resources, including coal, but these investigations have been carried out independently of each other.

In May 1988, the Mining Technical Committee was formed to co-ordinate research and development funding among federal and provincial governments and private organizations in the area of coal production technology.

Members of the technical committee[1] represented coal producers, research and development agencies, and the Alberta and federal governments.

The committee identified the following priority areas for investigation:

- mining costs;
- optimal recovery of resources; and
- product quality.

The committee co-ordinated mining technology components of various research projects, in particular those associated with reducing the delivered cost of western Canadian coal in Ontario.

Surface Geophysical Techniques for Foothills and Mountain Coalfield Exploration

The value of high-resolution geophysical methods for use in a plains setting was demonstrated in the Surface Geophysical Coal Exploration project. In a subsequent project funded by a joint venture group of companies led by Esso Resources Canada Limited , the objective was to test and evaluate the application of high-resolution, surface geophysical techniques for defining coal geology and mining targets in a variety of complex topographic and geologic settings in the foothills and mountain regions.

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[1] Like most technical committees formed to help guide government/industry coal research projects in Alberta, the Mining Technical Committee held meetings in response to the requirements of its members. At its most recent meeting in 1990, the following were represented: Quintette Coal Limited, Obed Mountain Coal Company Limited, Unocal Canada Limited, TransAlta Utilities Corporation, Luscar Ltd., Esso Resources Canada Limited, Luscar Sterco (1977) Limited, Fording Coal Limited, Smoky River Coal Limited, Smoky River Holdings Ltd., Crows Nest Resources Limited, Gregg River Resources, The Coal Association of Canada, CANMET, Ontario Ministry of Energy, Department of Western Economic Diversification, Alberta Geological Survey, British Columbia Mines, Energy and Petroleum Resources, Saskatchewan Energy and Mines, Alberta Environment, Alberta Culture and Multiculturism, and the Alberta Office of Coal Research and Technology, assisted by the Coal Mining Research Company.

While 50 years' experience with surface geophysical methods in petroleum and metal exploration suggests that suitable measurement technology is available, the applicability of these techniques in coal exploration is still unproven.

For example, it is known that high-resolution geophysical methods demand better-than-standard topographical surveys. Also, steeply dipping beds must be mapped with a dense network of measurement points. The large volume of data collected from such a program demands sophisticated data management and processing techniques. Therefore, if these methods are to be useful to Alberta's coal industry, they must be used to complement conventional drilling programs to ensure that the holes are drilled in critical locations. Projects designed in this manner can obtain more information than is possible with drilling alone.

In this three-year project[1], increasingly complex geological settings were investigated to accommodate the variety of geology and topography found in Alberta. The studies covered features such as folding, faulting, dipping strata and tectonically thickened coal under topography that varied from flat to rugged.

During Phase I studies carried out in 1988/89, seismic lines were run at the Smoky River and Coal Valley mines. The resulting reflection seismic profiles indicated structures generally consistent with the interpreted stratigraphy. The more complex topography at the Smoky River site, however, caused some difficulty in data processing. This led to the conclusion that better data on subsurface velocity control should be obtained from the downhole geophysical logs to ensure correct data interpretation. Also, additional work was warranted to refine and document the findings, as well as to compare the interpreted results with actual core findings. These activities were carried out in Phase II.

Phase II results from the Springhill coalfield in Nova Scotia showed that 5-m spacing of the seismic receivers (geophones) can provide better data than the normal, wider spacing in shallow depths. This reduced spacing was then used during the fieldwork at a mine near Telkwa, British Columbia. The interpretation of seismic data was confirmed by the on-site geology.

By the end of Phase II, the project had shown that useful reflection seismic profiles of the subsurface could be obtained in gently dipping, monoclinal strata underlying gently rolling topography, as well as in more geologically complex settings. The combination of several data manipulation techniques provided realistic geophysical information.

During 1990/91, Phase III work was carried out at the Coal Valley, Chinook South (Coleman), Mt. Leyland (Cadomin) and Quintette coal mines. Also, an evaluation was made of the costs of reflection seismic techniques versus conventional drilling methods.

New drilling at the Coal Valley site confirmed the presence of a thrust fault that was predicted from the reflection seismic profiles.

A reflection seismic investigation was carried out at the Mt. Leyland coal mine in complex, folded strata. The major coal seams were imaged successfully except in areas where the strata had a vertical or near-vertical orientation. Interference from diffraction patterns made it difficult to evaluate small-scale faulting.

Several geophysical techniques were tested at the Chinook South property of Manalta Coal Ltd. Included were: direct current resistivity profiling, fixed-frequency electromagnetic (EM) induction, max-min horizontal loop EM, very low frequency EM and gravity measurements. With the exception of very low frequency EM, each method provided useful information, and all the instruments were easily carried and applied by a small crew, even on fairly steep slopes.

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[1] Other participants were: Crows Nest Resources Limited, Manalta Coal Ltd., Smoky River Coal Limited, Quintette Coal Limited, Luscar Sterco (1977) Ltd., and the Office of Coal Research and Technology. Staff from both the Alberta Geological Survey and Geo-Physi-Con Ltd. contributed technical expertise to the project.

All the above techniques (except gravity measurements) were used at several sites of the Quintette coal mine. The results were similar to those obtained at Chinook South despite the ruggedness of the slopes at Quintette. Ground-penetrating radar was also tested at Quintette's Shikano Pit, but the equipment experienced frequent breakdowns.

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Contacts

More information regarding the use of reflection seismic methods to investigate coalfields is available from:

Dr. D.C. Lawton
Associate Professor of Geophysics
Department of Geology and Geophysics
The University of Calgary
2500 University Drive N.W.
Calgary, Alberta
T2N 1N4

Telephone: (403) 220-5841

Additional information concerning very low frequency geophysical techniques for coal exploration is available from:

Manager, Technical Services
Smoky River Coal Limited
P.O. Box 2000
Grande Cache, Alberta
T0E 0Y0

Telephone: (403) 827-3711

For more detailed information about the Surface Geophysical Coal Exploration and Downhole Geophysics projects, contact:

Andrew Hickinbotham
Fuel Supply Department
TransAlta Utilities Corporation
P.O. Box 1900
Calgary, Alberta
T2P 2M1

Telephone: (403) 267-7110

and

Mark M. Fenton
Environmental Research and Engineering Department
Alberta Research Council
P.O. Box 8330, Postal Station F
Edmonton, Alberta
T6H 5X2

Telephone: (403) 438-7522

More detailed information about the surface geophysical exploration project in the foothills and mountains is available from:

A.R. Peach
Senior Development Geologist
Esso Resources Canada Limited
238 - 4th Avenue S.W.
Calgary, Alberta
T2P 0H6

Telephone: (403) 237-2066

More can be learned about the Alberta Office of Coal Research and Technology by contacting:

Chairman
Alberta Office of Coal Research and Technology
Alberta Energy
11th Floor, North Petroleum Plaza
9945 - 108 Street
Edmonton, Alberta
T5K 2G6

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